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To: Mr. F.J. Kee
Director of Research

TRIP REPORT: MACHINE VISION WORKSHOP

David L. Mader

A government sponsored workshop brought together Canadian suppliers, users, and potential users of machine vision for an assessment of the role of this technology in an industrial strategy for Canada. The lectures and discussion covered the theoretical and practical sides of machine vision, as well as the status of the manufacturing sector in the Canadian economy. Four of the attendees were invited to come to Ontario Hydro to present their work and to discuss machine vision applications here on April 25, 1986.

INTRODUCTION

A "Machine vision technology and applications workshop" was held on February 11, 1986, at the Chateau Laurier Hotel in Ottawa. It was organized and chaired by Canadian Artificial Intelligence Products Corporation (CAIP) to air a report on computer vision that they have prepared for the Office of Industrial Innovation in the Department of Regional Industrial Expansion (DRIE). Invited participants included a number of suppliers of vision systems and related components, and existing users of these systems as well as potential users. There were also government representatives from DRIE, the National Research Council (NRC) and other users and supporters of vision systems. The author (Mader), who has been active in computer vision research, attended instead of Dr. A.C. McMillan who had received the official invitation in her capacity as the Divisional Research Proposal Officer.

This report was written as a means to introduce a wider audience at Ontario Hydro to the area of machine vision, to suggest possible applications of machine vision at Hydro, and to announce an upcoming workshop at the Research Division with speakers invited from companies in machine vision.

SPEAKERS

A sobering introduction on the prospects of the manufacturing sector in the Canadian economy was delivered by Rick Bower of DRIE. He had just returned from a trip to the

far East and reported that he saw fully state-of-the-art factories in Korea where workers put in 60 hours a week and were paid $400 per month. The factories are highly productive, being in operation 24 hours per day, 6 days per week. Thus it appears that off-shore manufacturing is beginning to outclass domestic manufacturing. On the intellectual side, Bower reported that in India, computer programmers with US training or equivalent were available to work for $3000 per year. Thus the advantage in know-how possessed by Canada (and the US and Europe) is rapidly receding. **However, to counter these trends it appears that DRIE is eyeing machine vision and computer vision as a special niche which should be pursued in Canada.**

The first technical presentation, by Steven Zucker of McGill, gave an introduction to computer vision, outlined what is being done in practical systems, and pointed out some of the limitations in going to exotic systems. Machines are nowhere near being able to see like people. Even crabs can maneuver over the ocean floor around obstacles better than any machine. So practical vision systems for industry should be thought of more as sensors or measuring instruments than as all-seeing eyes.

Colin Archibald of Machine Vision International showed image processing that can be done on their Image Flow Computer. Images can be ordinary ones such as knots in wood, or X-ray images of fish, for example. One of their systems has increased the quality of canned green beans by 200%. A vision system spots stones and stems and directs a jet of air to blow them off of the conveyor belt. In printed circuit board evaluation, machine vision inspection has increased the quality to the point where Hitachi can now offer a 20 year warranty on consumer electronics. Turning to implementation of this new technology, one impediment found by Archibald is that **domestic decision makers are too distant from the technology to be able to distinguish between sales hype and genuine opportunity**. Accordingly his company insists that at least one person in a client company be trained in the technology.

Tim Pryor of Diffracto Limited gave a talk on the manufacturing sector and machine vision. He sees machine vision as sensors for metal forming machines to measure the parts being produced so that the forming machines can be adjusted on-line to continuously produce high quality parts. Taking it further, he called for intelligent use of these new sensors in an overall strategy of designing and making parts. The big pay-off case he cited was a $2 saving per car when Ford found that they could eliminate a steel liner in a hydraulic cylinder thanks to a vision sensor that was good enough to weed out any aluminum housing flawed by porosity. Turning to machine vision as eyes for robots, Pryor aired a video tape which showed an adaptive five degree-of-freedom robot tracking a swinging pallet, using Space Arm technology invented at the National Research Council. Invention of a new spin-off from this was described, Diffracto Sight, which makes deformations of surfaces readily apparent even to the untrained eye. A transcript of part of his talk is given in the Appendix.

Peter McKnight presented an overview of CAIP's report for the government. One point that stood out was the role of government procurement. One of the best ways the government can support new companies is to buy their products. Not only does this help the company's finances, it gives them technical targets to shoot at and achieve. It provides them with a testing ground. Even if the product does not work out immediately, what the company has learned will be valuable later on.

A ROLE FOR MACHINE VISION AT ONTARIO HYDRO

Attendance at the CAIP workshop strengthened the conviction that there should be a role at Ontario Hydro for a new technology that can give a 20 year warranty on consumer electronics, improve the quality of canned green beans by 200%, take $2 off the cost of a car part, or grapple a moving satellite. To facilitate adoption of this technology, an in-house workshop on machine vision is planned as described in the next section. To stimulate thought on possible applications, a few illustrative suggestions for machine vision at Hydro are given next.

Surface deformations. Bulging of capacitors may point to ones that should be replaced, so a ground based sensor that can identify bulged capacitors at service height would be useful.

Condition of tube IDs. Pitting of pressure tubes, for example, is a condition similar to porosity in aluminum bores and could perhaps be detected similarly.

Wood poles. Measurements could be made on cross sections of pole samples. A binary vision system can look at a silhouette and find the area, perimeter, eccentricity, number of holes, etc. A more advanced gray scale vision system could look at the surface of the cross section and count rings. Ring count would help to determine if low breaking strength was due to decay or rapid tree growth.

Irradiated fuel inspection. Computer vision systems can be programmed to enhance visual inspections by providing measurements on designated features. A simple example would be to measure the distance between two designated points; this would give the length of a scratch, for example. A similar treatment could be envisioned for areas, which could be burns, discolorations, or wear patches.

Personnel tracking. The cumulative electro-magnetic exposure dose received by a lineman could be calculated provided his position relative to the wires was measured continuously. With a vision system the operator could designate the wires on the image at the beginning of the session and could designate the lineman continuously. Or the lineman could wear special clothing such as a red hat, green gloves, and blue boots so that a colour system could easily detect his extremities.

A number of similar applications of a man-tracking vision system could be envisioned.

Welding: cavity measurement, seam tracking, weld deposit. There is a program in automated welding research at Ontario Hydro with needs in cavity profiling, seam tracking, and weld deposit measurement.

Voids in concrete. Void count and characterization in concrete is a labour intensive chore when done manually. Features which can be extracted by existing binary vision programs are: area of void, perimeter, eccentricity, and major and minor axes. Statistical information could be accumulated automatically.

Large stand-off optical triangulation for wire sag. Sagging of wires can be measured by optical triangulation, provided the sensor head can be located at a safe distance. With the design flexibility that optical triangulation has to offer, the required stand-off for voltage safety and the required measuring accuracy could be achieved.

Rotor-stator gap monitoring. In large diameter hydraulic generators there is a need to monitor the air gap between the rotor and stator.

Shaft run-out. Run-out of motor and pump shafts and couplings could be measured by optical triangulation as a permanent monitor or as a check on existing sensors.

Clearly, there are possibilities to use vision sensors and computer vision in inspection, measurement, surveillance, and elsewhere.

ONE DAY WORKSHOP AT ONTARIO HYDRO

A one-day workshop on machine vision is planned at the Research Division for April 25, 1986, to be held in the Auditorium. Four participants from the CAIP workshop named below were invited to visit Ontario Hydro and give talks in the workshop:

1. Colin Archibald, Machine Vision International, Ottawa
2. Keith Arner, Clay-Mill Technical Systems Inc., Windsor
3. Forrest Livingstone, Hymarc Engineering Ltd., Ottawa
4. Tim Pryor, Diffracto Limited, Windsor

The objectives of the workshop are to:

(a) Inform Ontario Hydro staff and managers about the role of machine vision in monitoring, measurement, surveillance, and robot control.
(b) Identify possible machine vision applications at Ontario Hydro.
(c) Foster a sense of cooperation to enhance the rate of adoption of the new technology of machine vision at Ontario Hydro.
(d) Explore roles and relationships for Hydro staff and outside firms for effective implementation of machine vision.
(e) Hold preliminary discussions on possible projects.

To gain the maximum benefit from the workshop it is recommended that Hydro participants come prepared to air potential applications.

A notice of meeting will be circulated later.

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APPENDIX

TALK BY TIM PRYOR

Hi, my name's Tim Pryor. I'm chairman of Diffracto Limited located in Windsor, Ontario. Our company is in the machine vision business, which to many people means inspection of car parts, or eyes for robots.

First, the **bad news**, and then the good news.

An example of the need to keep abreast of the new technology in Canada is as follows. We sold one of our sensors to a systems integrator who put it on a milling machine at Rock Island Arsenal, US Army. With adaptive control, the productivity of that machine went from one howitzer recoil tube per shift to five. The quality went from 5 thousandths of an inch total tolerance to one thousandth, another factor of five. Now I submit to you that the dollar in Canada can't go low enough to make up for machines like that in another country. So if XYZ tool company turning out recoil tubes in Mississauga has competition like that, he's had it, he's through. **One day he'll find he doesn't get his usual order. It's too late then. It's way too late.**

These things we've been talking about, the educational system, the infrastructure, take years. It's getting too late. It's almost all over.

I know this makes it sound like doom and gloom, but I don't know any other way to say it. **Even having a low dollar may not save the day, though it'll prolong the death.** Because as the dollar drops the Canadian who has to buy the machine in the States sees the price of the machine go up. So if the operation he's doing is heavily machine dependent he's no better off with a low dollar, he's worse off.

Some sort of industrial strategy is absolutely needed in this country. I've lived in this country for 20 years now and every year or two there's a study and we always hear the same thing, "We need an industrial strategy." Well, time is running out.

Now what can you do for a strategy? Well dogone it, our company is a living breathing example about the wisdom of people at the National Research Council and the Department of Industry who over the years, before vision ever became popular, gave us little grants to help do R&D in these sectors. And those little grants over the years, by people who had the foresight to see that it might be needed some day, were really what made Diffracto now.

Machine vision is a key sector, there's no question about that. It's the key, I would maintain, to machine control, to robots, to welding. And it's the key to flexible manufacturing; it's the key to a lot of things you read about. The manufacturing community was dealt a bit of a flier on all this business about CAD/CAM. CAD/CAM is **not** where it's at. It's the **making** of the parts that counts. The designing bears a very small relation to Canada's well being.

In our area of machine vision (which is a different area from the people that just spoke before me) we are a world leader. We have 200 patents. We sell our products worldwide. And the key issue is that we help other people make their machines better or their processes better.

And so I maintain that we could take all these things and sit down and optimize Canada's future.

And now the **good news** part.

I'm going to make this the good news part; I'm going to give it a Canadian booster flavour, because I'm going to talk about two other companies: Clay-Mill Technical Systems in Windsor whose representative Keith Arner is here. This one is a case of a little bit of vision sensors helping a Canadian company get a huge order. The largest assembly-robot order in the world has been placed with Clay-Mill Systems in Windsor. Why? Because they had the requisite pieces of the puzzle in how to put a car together. One piece was the machine vision sensors that we supplied.

Another one is Servo-Robot which is Jean-Paul Boillot over there. They are taking an NRC developed sensor which has some nice features for a hazardous environment that has a lot of optical noise, and using it to adaptively control welding. And they are going to do really well, I think, simply because they are doing it the right way, the nice solid technical way.

Then I'm going to talk about another NRC sensor for the Space Arm that we have that turns out to have benefits for remote vehicles and mines and tractors and goodness knows what else. Then I want to talk about a little invention that we had in Windsor that is having all kinds of repercussions and may be the world's simplest vision sensor: Diffracto Sight.

Before that, there's a point I always harp on: there's **vision** and then there's **working vision** and sometimes the two are not the same. On the plant floor if it doesn't work about **99%** of the time in an inspection application, and about **99.9%** of the time in a manufacturing application, say, to guide an assembly robot, you're in big trouble. It's almost moonshot reliability. In particular when there's a lot of sensors and computers, the whole ensemble has to work at 99.8 or 99.9%, or the whole thing is going to be thrown out.

Slides

The use of machine vision on the plant floor is to locate and position so other machines can do their job, and to see like humans - this is the inspection job. Here are some vision sensors in an inspection station that are checking how the pieces of a car body are fitting together. We don't check just the final car - we check the underlying pieces too because if the final outside pieces don't fit you have to find the culprit down below. Sometimes the sensors have to be off in the distance, perhaps three feet, and it still has to be able to measure to about 0.1 mm or 4 thousandths of an inch. So there is some pretty sophisticated work going on to pull out the accuracy levels.

Now here is Clay-Mill's application. Keith is here so you can ask him questions. Here are our sensors. The car body comes to this station before the doors and trunk lid are put on. It comes to a stop to within an inch or so. The idea is to locate the body accurately and to guide in a robot that will pierce mounting holes in the right places for the doors and trunk lid. That is an application that has been talked about for years. As far as I know, Clay-Mill is the only company in the world to ever get an order, and a big order too.

Again, we have sensors plus robots right here in Canada. This is the good news part. Canada can do it. But Clay-Mill is the exception. They took a big risk. As Colin said earlier you don't get much of this in Canada, and we see it too. In fact our guest book is an indicator. Honestly, apart from GM Canada who is our investor, if we get one visitor in a hundred from Canada that's doing good. The interest level generated in Canadians is low. And so the education aspect, getting the message around, is just getting started. This meeting is a good first blush at it.

Here is an inspection unit right next to a press unit. The idea is to get more statistics to control the press. The more data you have, and the more confidence you have in that data, the better you can control the process.

Now the main argument for machine vision, at least according to me, is not just to replace a human, it's to control the process. That's where you get the major benefit.

Another project we were helped out with by the Department of Industry in a defense sharing arrangement in the early '70s was to measure turbine blades. That's one of the Space Shuttle's turbine airfoils we checked out at Rocketdyne. There's the laser spot of light on the blade. It tracks around the blade and measures it using triangulation. This is a mechano-optic solution to the problem of making noncontact measurements to high accuracy. If you try to look at one of these parts with a camera in a computer vision system, you may not get the accuracy you need. So sometimes a mechano-optic solution, that is, to track a point of light around the part, is the better solution.

There's a large machine for turbine dimensions and alignment in turbine rebuilds. We don't do just auto parts at Diffracto.

Here's gears. At Ford Motor Company all rear axle gears are checked. Our gage is the final arbitrator of quality for these gears. It took three years of testing to prove that we were getting the right answer. And that the old-style equipment that they had was wrong. So sometimes getting your equipment accepted can take quite a long time.

And here's one of the all-time winners of machine vision payback. This is inspecting rack and pinion power steering housings. There is a rack that goes through the housing and a hydraulic piston that drives it one way or the other. Before we came along, they were pressing a steel sleeve into the aluminum housing in order to be sure that there was no porosity in the housing that could eat away at the seals. We were given some prototype money, in this case by Ford, to see if we could detect defects in the aluminum bore. And we did, and it worked. This was installed in 1980 and has been running ever since.

They were able to redesign the part and eliminate the steel sleeve. This saved two pounds of weight out of the part. And more importantly two dollars a car was saved. Considering the millions of cars that Ford makes, they saved enough to pay for all of the equipment they ever bought from us, even if they threw it all out on the trash heap. That one paid for all the rest.

Optical sensing, machine vision, and computer vision offer prospects for major savings. If you can use intelligent sensing to make a part in a new way, or design a vehicle or assemble it in a new way you can really save money. It's not just replacing people, not at all.

One of our exciting projects is to take the NRC Space Arm guidance system and use it for industrial applications. And in the course of this work we found you could take some of the target material and lay it on a car body and look at it in a new way. That lead to the invention of Diffracto Sight. With these glasses you can look at a car body and see all the defects in the pressed metal and plastic moldings in one go. It's never been done before.

There's a Pontiac as you see it under normal lighting. There it is with Diffracto Sight. What it has done, in a way that is not yet fully understood technically, is to magnify local geometrical form distortions. It works in a way that shows up the local waviness, but leaves the rest of the image alone. It is a purely optical process; there is no computer in it at all. Anybody can look through these glasses and the defects jump right out at you. For that very reason everybody has to have one. Mold shops, die shops, plants at every level are buying them. And of course we are moving now to automate it and put numbers on it.

There's a Merc. Now there's damage on that car that apparently the factory didn't catch. Also notice the glass up there. The glass shop needs help too; they are not making it properly. You can see the waves in it. We have seen Lincolns with pieces of masking tape stuck on and painted over.

There is a great deal more to come. When you can analyze these images and feed them back into the process there will be great savings. Not only in the parts plants, but in the die shops and mold shops as well. So we expect the savings of this to be very, very high.

Here are a few more things. This is a bomb for the US Navy. You shoot it up in front of an attacking missile and there's 100 pounds of TNT to burst it into shrapnel. To get good shrapnel these grooves on the inside have to be right and that's what this contouring gage is checking. Here is a Pontiac crankshaft. All the finished dimensions are being checked to 20 millionths of an inch. There are 55 sensors in that unit. This is a flexible gage for motor shafts for General Electric in Fort Wayne. This goes in a turning cell where robots load the gage and check all dimensions and parameters and feed the data back into the machines. Again, process control. This is a wrist pin being checked to 10 millionths of an inch. One is being checked every second. And here is one of our more exotic projects - checking sphericity and diameter to 2 millionths of an inch on a gold plated air bag sensor ball.

Video Tape

This is the only known dynamically adaptive robot project in the world. It is an off-shoot of the Canada Arm which has to grab a moving satellite from a moving Shuttle. It is fully adaptive, and it is fully operational, too. And there are uses in mining, and space, and tractors in fields. We have projected all manner of uses.

In the video tape we see a robot whose job is to pick a part off of a parts carrier hanging from a moving overhead conveyor. A man behind the scene is poking the carrier with a broom handle to make it swing and the hand on the robot is following the motion of the part in five degrees of freedom, poised to grasp it. The system uses a target of special material attached to the carrier and the vision sensors recognize its location and orientation to supply navigational input to the robot.

This technology is the next wave for robots, and in fact it is required for space station activity going out to the year 2000. Near term payoff is improving robot calibration and it al-

lows us new ways to build the tooling to assemble cars, ships, and airplanes. In the 1990s we can think of seeing tractors on farms being guided this way. The targets could be on the barn or down at the end of the field and the camera on the tractor. It could be used to land helicopters on ships bucking in high seas.

It could be used in construction where you are driving a crane over sinking mud or are trying to unload a pallet of bricks from an unstabilized truck.

Indeed the technology first started by the National Research Council for the Space Shuttle seems to have almost unlimited potential. It's a credit to the people at NRC and to Canada that this unique approach has been taken and we feel pleased and thankful that we are a part of it.

Finally, there is another angle. As a result of this work another invention, Diffracto Sight, was made in a totally separate field. This invention would not have happened had we not been working on the Space Arm technology. These unanticipated benefits are one of the compelling reasons to continue doing research in industry and at universities.